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Reduced urban traffic and emissions within urban consolidation centre schemes: The case of Bristol

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Abstract

Urban freight consolidation centres (UFCCs) can provide a significant contribution to reducing the negative impacts of freight transport to city centres whilst at the same time providing a more seamless, higher-value logistics experience for their users. The paper draws on the experiences of the Bristol-Bath freight consolidation centre (BBFCC), established in 2002 to serve Bristol city centre and uniquely extended in 2011 to cover Bath, each served by electric lorries; it appraises the benefits of shared ‘final mile’ freight services, presenting a model for the evaluation of the reduction in traffic and polluting emissions based on Bristol, with a view to optimising future UFCC design. Data about the number of deliveries made by heavy goods vehicles (HGVs) of different types to the BBFCC and the number of deliveries made from the BBFCC to the two shopping centres covering a period of 17 months are analysed. The correlation between the type and number of HGVs delivering to the BBFCC and the number of deliveries made to the retailers by the BBFCC is explicated by means of a multiple linear regression model. Its development is based on analysing parameters as R Square value (total and adjusted), F-statistics and p-values for each coefficient. An estimation of the number of HGVs re-routing to the BBFCC and the pollutant emissions avoided in the urban centre is appraised. The pollutant emissions reduction is based on factors drawn from the UK National Atmospheric Emissions Inventory. Results suggest that the proposed approach may yield HGV movements avoided in Bristol city centre of 75.5% on average. Also, by considering the whole study period, reductions amount calculated is equivalent to 28,677 Kg of CO₂, 122.29 Kg of NO_x, 2.31 Kg of PM₁₀, 20.32 Kg of CO and 9,854 Kg of fuel. Nevertheless, emissions reductions are significant, but currently limited by small scale, due to the low number of participants. Emissions reductions in the host cities are identified as a result of sharing delivery vehicles for the final leg. The regression model showed high correlation coefficient values (over 85%) for deliveries to the Bristol city centre thanks to the BBFCC. The linear regression models developed provide a useful tool for local authorities

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and logistics/transport planners in optimising the planning of UFCCs to reduce freight traffic, associated emissions and to improve logistics and transport performance.

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1. Introduction

Freight transport and distribution represent a strong tool for the social and economic development in the urban context, but also a serious problem in terms of negative externalities. In fact, it is responsible for increasing congestion, pollution and reducing the quality of life for people that live in and visit cities. In sum, it is responsible for increasing the economic, social and environmental costs of transport. The Urban Freight Consolidation Centre (UFCC) concept emerged to reduce the negative impacts caused by freight transport in city centres while ensuring an efficient freight distribution with high added value. UFCCs aims to relieve congestion through a process which involves the goods destined for the city centre being delivered to a remotely-located UFCC where they are consolidated into a single delivery made by a high load-factor vehicle in order to reduce the number of heavy good vehicles (HGVs) circulating in the urban area and so improve air quality.

According to Comi and Rosatia (2012) “today, there is a growing interest to support systems able to support decision-makers to understand the structure of freight urban system”. However, despite the evident benefits related to the UFCC schemes, their use is not widespread due to financial issues: the initial public funding for the feasibility studies and trials that are generally required to support the initial phase of operation limit their development. Also, city logistics systems have high complexity and the lack of knowledge of logistics, as well as organizational-restrictive conditions, limit their implementation by the municipal authorities (Jarosław and Maja. 2012).

The paper presents an original model for the evaluation of the relations between vehicles-in/vehicles-out and the reduction in traffic and polluting emissions, based on the experiences of the Bristol-Bath Freight Consolidation Centre (BBFCC), with a view to optimising future UFCC design. The BBFCC, on which the evaluation is focused, started working in 2002 with support from the European Project Civitas VIVALDI: the deliveries were made to the city centre of Bristol. Later, in 2011, the logistics service provided by the BBFCC was extended to cover a second neighbouring city centre. Bath. The BBFCC offers high value-added services and makes the deliveries by means of electric lorries. The model proposed in this paper analyses data collected for the CIVITAS Renaissance project and also provided by the operator of the BBFCC for a period of 17 months. The number of deliveries made by different types of HGV to the BBFCC and the number of deliveries made by the BBFCC to the two shopping centres are examined in order to evaluate the number of urban HGV movements avoided and the related pollution reduction.

2. State of Art: the overview of the phenomenon

The EC has attributed the transport sector within being the largest cause of unsustainability. Road transport is the main cause of this: it is the main mode used and the most polluting. The demand for freight and passenger transport is qualitatively more exigent and quantitatively growing more and more (EC. 2010). Thus, new regulations and policies to increase the sustainability of this sector are needed. For these reasons the EC has proposed a policy of promoting “best practice” for urban transport.

The factors influencing fuel consumption can be divided into five categories: vehicle, environment, traffic, driver and operations (Demir et al, 2014). Most fuel consumption models are focused on vehicle, traffic and environmental influences and they do not consider driver related issues which are relatively difficult to measure (Demir et al, 2014).

It can be assumed that CO₂ emissions are directly related to fuel consumption and therefore can be easily calculated if the amount of fuel consumption is known (Demir et al, 2014).

According to Hickman et al. (1999) transportation emissions and energy consumption for heavy goods can be calculated by means of a methodology called MEET, based on on-road measurements. This model has been widely used by several researchers as for example, Kim et al. (2009) who investigated the relationships between freight

transport costs and CO₂ emissions in intermodal and truck only freight networks. Also, Figliozzi (2010) used it to study the minimization of emissions and fuel consumption. MEET has been used also by Pan et al. (2010), who analysed the effect of pooling supply chain networks on the reduction of transport-related CO₂ emissions.

An important macro-model was defined by National atmospheric emissions inventory (NAEI). It was developed for a large range of sectors including agriculture, domestic activity, industry and transport (NAEI, 2012). It uses a combination of total fuel consumption data and fuel properties, or from a combination of driving-related emission factors and road traffic data to calculate emissions related to road transport. As the same, NAEI allows calculating polluting emissions produced by vehicle type and for specific speed and traffic/road conditions. This model was applied by Maden et al. (2010) to the vehicle routing and scheduling problem with the aim of minimize the total travel time under congestion. Most studies in the field of green road freight transportation have focused on a limited number of factors, mainly vehicle load and speed (Demir et al., 2014). According to Demir et al. (2014) “there exist only very few studies carried out within the perspective of fuel consumption and emissions”. Undoubtedly, the sustainability of urban areas is highly compromised by transportation, and the number of research and demonstration projects concerning urban mobility has increased (Lindholm and Blinge. 2014). Urban freight movements contribute to the unsustainability of urban areas. They represent the so-called ‘last mile’ of the supply chain and are often the part of the supply chain with the highest costs (Chopra. 2003). Thereby, not only local authorities – which are responsible for emission and safety standards – but also transport operators - for economic reasons - are interested in making this final link in the delivery chain as efficient as possible.

Considering Europe overall, the number of freight vehicles in urban areas has rapidly increased in recent years and this trend contributes, as already noted, to congestion, air pollution and noise, but also to the inflation in consumer prices, due to the increase in logistics costs due to congestion (Russo and Comi. 2010). According to Lindholm and Blinge (2014), “from this perspective, it is obvious that the authorities need increased knowledge on how freight transport affects the economic growth of a city, and how possible regulations and policies affect the transport companies and their profitability”. Urban economic competitiveness - both in terms of the income generated and employment levels - can increase as a result of a more efficient freight distribution system (Russo and Comi., 2010). This is a further reason why policy makers should intervene in order to manage the flow of goods more effectively, by means of ‘city logistics’ approaches, such as UFCC. Brown et al. (2005) defined an UFCC as “a logistics facility that is situated in relatively close proximity to the urban area that it serves be that a city centre, an entire town or a specific site such as a shopping centre, airport, hospital or major construction site”. Electric vehicles can be well suited to the UFCC delivery cycle, due to its relatively short and predictable routing. Electric vehicles are particularly energy efficient and pollution avoiding in slow-to-medium speed, stop-start traffic conditions. According to Melo et al. (2014) “promising results have been reported with the increasingly popular initiative of the use of small sized electric vehicles (SEV), due to their improved energy efficiency, local zero emissions and lower traffic disturbance”. The UFCC concept aims to reduce the number of HGVs in urban areas and the overall distance travelled by them by improving the load factor of goods vehicles both delivering from the UFCC and into it as well. Hence, it also promotes reducing polluting emissions and greenhouse gas emissions associated with these - both through reductions in the total distance travelled, and through the use of low emission vehicles – (Brown et al., 2007). However, there is a gap in the literature in terms of modelling these flows of vehicles, goods, energy and emissions.

3. Methodology

Through the case study presented in Section 4, the correlation between the number and different type of HGVs that make deliveries to the UFCC and the number of deliveries made to Bristol city centre from it is estimated. Reflections are also made on the reductions in polluting emissions as well as in the number of vehicles required as a result of adopting the consolidation scheme. While in Nuzzolo et al. (2012) they find an aggregate logit model (regardless of the transport service type) with three alternatives (i.e. one stop, two and more than two stops), the proposed model is based on a multiple linear regression model with $k=4$ independent variables, by means of which the correspondences between dependent and independent variables are analysed. The choice of using the linear regression model is due both to its ease in representing the correlation between variables involved in the process and the clarity with which its results can be read.

According to Gujarati (2012), “regression analysis is concerned with the study of the dependence of one variable, the dependent variable, on one or more other variables, the explanatory variables, with a view to estimating and/or predicting the (population) mean or average value of the former in terms of the known or fixed (in repeated sampling) values of the latter”.

As the independent variables are more than 1, the author proposed a multiple regression analysis which is “regression analysis conditional upon the fixed values of the regressors, and what we obtain is the average or mean value of Y or the mean response of Y for the given values of the regressors” (Gujarati, 2012).

The model proposed in this paper is developed by the following linear equation:

$$Y = b_0 + b_1 * X_1 + b_2 * X_2 + b_3 * X_3 + b_4 * X_4 \quad (1)$$

Y = n. of deliveries made by BBFCC to city centre expressed in terms of n. of stores visited per period considered;

b₀ = interception which is the value that Y has when all the X_j variables are equal to zero;

X₁ = n. of articulated vehicles that made deliveries to BBFCC;

X₂ = n. of 18t vehicles that made deliveries to BBFCC;

X₃ = n. of 7.5t vehicles that made deliveries to BBFCC;

X₄ = n. of light goods vehicles that made deliveries to BBFCC;

b₁, b₂, b₃, b₄ = variable coefficients (they indicate how Y changes on average when X_j increases by one unit considering that the other explanatory variables have constant values). The coefficients are estimated on the basis of n data.

Correlations between HGVs and number of deliveries made by BBFCC are made by considering two different sub-models:

- Model A: a value equal to zero for the interception is assumed. In this way, if X_j equals zero, also the Y value is equal to zero. In other words, if no deliveries are made to the BBFCC, the latter does not make any deliveries to the retailers.
- Model B: the interception value in the multiple linear regression model is different from zero. Thus, if X_j equals zero, the Y value is not equal to zero. In other words, even if deliveries are not made to the BBFCC, the latter still makes deliveries to the retailers anyway.

The model highlights the relationship between the deliveries made to the BBFCC by HGVs (per type) and those made by BBFCC to the retailers. Its development is based on analysing classic progressive parameters: R Square value (total and adjusted), F-statistics and p-values for each coefficient. Reductions in terms of pollutant emissions and the number of HGVs are calculated in the “Results” paragraph by means of the following formula, through which it is possible to calculate the changes (in grams) of CO₂. NO_x. PM₁₀. CO and fuel reductions for the period examined:

$$Ek_{poll} = \sum (V_i * I_i) - \sum (V_j * I_j) \quad (2)$$

Ek_{poll} = total emission reduction related to each polluting element

k = polluting elements (CO₂. NO_x. PM₁₀ and CO)

i = Polluting vehicles (articulated vehicles. 18-tonne vehicles. 7.5-tonne vehicles. vans)

j = Consolidation Centre vehicles

V = number of vehicles

I = Emission factor

It is possible easily calculate the total emission reduction related to each polluting element by equation (2). It has just been calculated the pollution that would have been produced if the polluting HGVs have accessed to the city centre to make the deliveries (V_i * I_i). Therefore, it is possible achieve the emission reduction by subtracting to this rate the polluting emission produced by the BBFCC vehicles to make the same deliveries to the city centre (V_j * I_j).

Emissions and fuel reductions have been calculated using the UK National Atmospheric Environmental Inventory (NAEI), which gives figures relating to emissions per kilometre travelled by vehicle type. Polluting emission rates are calculated by taking into consideration the specific context of driving and average speed, in particular they are calculated for hot exhaust and cold start emission factors by vehicle type. This methodology however does not take into consideration the origin and final destinations of delivery vehicles, which might make a detour to the consolidation centre located in Avonmouth (i.e. not in the immediate outskirts of Bristol). Detouring will to some extent result an increase in emissions and fuel consumed compared with a shortest-path routing to the city centre. However, as the additional distance would be travelled on the strategic extra-urban road network and not on urban roads, even in the worst case whereby additional emissions and fuel consumption are caused, it can be argued that these would generally have a lesser impact in terms of exposing citizens to poor air quality and the actual quantities involved would be smaller than if the same distance were travelled on a urban road (more likely to have longer periods of stop-start congested driving conditions).

4. Application

The model proposed in this paper is based on the case study of Bristol, which analyses the impact of introducing a city logistics scheme to reduce traffic, energy consumption and polluting emissions related to freight transport in urban areas. The model implementation was carried out using data collected by the consolidation centre manager during the study period, for 17 months (from January 2011 to May 2012). The European Union financed this scheme to propel the mobility and environmental sustainability. The BBFCC has been involved in the following projects: CIVITAS VIVALDI (2002-2006), START (2006-2008), CIVITAS RENAISSANCE (2009-today).

BBFCC serves the Broadmead and Cabot Circus shopping areas in central Bristol and the central shopping area of Bath. The goods delivered are non-perishable and exclude potentially hazardous items requiring specialised handling (gas canisters, cooking oil, pressurised kegs) and very high value products. Following the ending of the 'pump priming' phases when the Centre was supported with European grants as well as local authority subsidy, the retailers which take part in the scheme pay a fee for the service. The deliveries are received at the BBFCC Monday to Friday, with onward deliveries into central Bath and Bristol made daily. The number of HGVs that made the deliveries to the BBFCC was recorded day by day for the study period, enabling the construction of a 357-row matrix (250 days for the whole of 2011 and 107 days for the first five months of 2012). The matrix takes into account the number of deliveries made to the BBFCC by HGVs and the number of retailers which have been visited by the BBFCC vehicles for the 'last mile' deliveries. Non-working days (Saturday, Sunday and Holidays) are excluded to the analysis. HGVs that make the deliveries to the BBFCC are classified in articulated vehicles, 18-tonne vehicles, 7.5-tonne vehicles and vans. In some cases a vehicle might have made a delivery direct to a retailer in the city centre not taking part in the consolidation scheme as well as visiting the BBFCC. Therefore, in order to understand the extent to which freight vehicle trips were being completely removed from the city centre, when a vehicle delivered to the BBFCC the Consolidation Centre staff noted the vehicle type and established through discussion with the driver whether or not the vehicle had made, or would make, other deliveries to Bristol city centre that day. Hence the HGVs which delivered to the BBFCC could be summarised in two categories:

1. HGVs that made deliveries to BBFCC but passed through Bristol city centre anyway (to make deliveries to other store(s), not part of the consolidation scheme);
2. HGVs that make the deliveries to BBFCC and do not pass through Bristol city centre to make deliveries.

Category (1) HGVs were excluded from the analysis as they in any case produce polluting emissions in Bristol as result of making other deliveries.

The study period started in January 2011 and ended in May 2012. At first, the authors analysed the whole period (case 1). Then we thought to use different sub-periods to understand how results could change for different days of the week (cases 6 – 10), or for a specific reference period of 1 year (case 2), or for a specific set period of 5 months in different years (cases 3 and 4). So, the authors could compare different results for each case and they could be able to make comparison between the different sub-periods and they achieved a specific equation that described the relations between dependent and independent variables by considering different period scenario. The BBFCC

manager can have an idea about the characteristics (number and kind) of HGVs that arrive to the consolidation centre and the number of deliveries that are related to them by analysing them day by day and so he can forecast the arrivals and plan the deliveries to the city centre.

5. Results

5.1. Regression analysis results

The linear regression model was applied to the matrix data and the analysis is articulated in ten different cases. Each case refers to a different timeset taken from the whole study period, with the number of operating days related to the specific case indicated in the right-hand column. The linear regression model coefficients are calculated by considering Model A (interception value equal to 0) and Model B (interception value not equal to 0), as discussed in Section 3. They are applied to the 10 cases. Results are shown in table 1 and 2.

Table 1. Model A: interception value not equal to zero. Variables coefficients values, R Square, Adjusted R Square and F-statistic values per case

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Observations	357	250	99	107	206	49	50	51	49	52
R Square	0.489	0.524	0.823	0.420	0.643	0.280	0.507	0.555	0.465	0.607
Adjusted R Square	0.484	0.516	0.816	0.397	0.636	0.215	0.463	0.516	0.416	0.573
F- statistic	84.439	67.418	109.423	18.452	90.428	4.283	11.574	14.350	9.561	18.141
Significant F	3.321E-50	2.111E-38	0.000	0.000	0.000	0.005	1.517E-06	1.120E-07	1.185E-05	4.510E-09
b0	4.922	4.663	0.659	4.724	1.533	8.316	2.093	8.403	4.925	11.372
b1	2.782	2.609	3.432	2.795	3.410	1.129	4.424	2.481	2.854	0.722
b2	2.726	3.049	2.690	3.358	2.137	1.745	1.682	1.495	3.809	1.904
b3	2.050	2.099	1.873	2.020	2.773	0.282	0.880	2.074	1.232	2.436
b4	0.726	0.431	1.494	1.445	1.748	1.406	1.510	1.432	-1.237	-0.063

Table 2. Model B: interception value is equal to zero. Variables coefficients values, R Square, Adjusted R Square and F-statistics values per case

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Observations	357	250	99	107	206	49	50	51	49	52
R Square	0.919	0.913	0.963	0.942	0.943	0.891	0.863	0.948	0.923	0.945
Adjusted R Square	0.915	0.908	0.951	0.931	0.936	0.862	0.833	0.923	0.896	0.921
F- statistic	997.060	647.937	611.382	418.846	831.468	92.231	72.626	214.241	135.363	207.849
Significant F	1.587E-190	5.689E-129	2.392E-66	2.458E-62	8.705E-124	8.353E-21	4.791E-19	4.183E-29	3.985E-24	3.047E-29
b0	0	0	0	0	0	0	0	0	0	0
b1	4.322	4.048	3.625	4.028	3.840	3.527	4.760	4.695	4.459	3.558
b2	3.605	4.074	2.846	3.765	2.383	4.055	2.880	2.985	5.415	4.824
b3	2.496	2.431	1.915	2.825	2.976	1.137	1.251	2.394	1.554	3.708
b4	0.885	0.469	1.500	1.880	1.870	1.509	1.691	1.969	-0.932	-1.102

R Square values for Model A are too low; there is no correlation between the deliveries made by the BBFCC to the Bristol city centre and those made to the BBFCC with Model A. No deliveries are made to the retailers when HGVs do not make deliveries to BBFCC. It suggests a cross-dock (vehicle-in-vehicle-out) approach as the most

The use of an electric vehicle for most deliveries resulted in reductions in number of HGVs in the city centre and so in pollutant emissions. In addition to the NAEI emissions factors, certain data supplied by the operator of the BBFCC were required to calculate the emissions reductions: BBFCC is located 8 miles (12.87km) from Bristol city centre, so approximately 16 miles (25.74km) were operated for each delivery round-trip.

Considering that deliveries were made by using both electric and diesel vehicles, the authors have calculated emissions and fuel reductions by comparing reductions actually achieved (“Real”) with reductions that could have been achieved if only electric vehicles were used (“Hypothetic”). Reductions have been calculated by means of equation (2) introduced in section 3. Data have been normalised per month in order to better compare results. The findings are shown in Table 4.

6. Discussion

The results highlight very low adjusted R Square values for Model A, hence there is no correlation between dependent and independent variables with Model A. It suggests a cross-dock (vehicle in - vehicle out) design for the BBFCC. The Fisher test results support discarding the hypothesis of random distribution of the coefficients and affirm that there is a linear relation between input and output values. On the other hand, high adjusted R Square values are achieved for Model B. The regression analysis allows defining the following equations (from 1 to 10 cases):

$$Y = 4.322 * X1 + 3.605 * X2 + 2.496 * X3 + 0.885 * X4 \quad (3)$$

$$Y = 4.048 * X1 + 4.074 * X2 + 2.431 * X3 + 0.469 * X4 \quad (4)$$

$$Y = 3.625 * X1 + 2.846 * X2 + 1.915 * X3 + 1.500 * X4 \quad (5)$$

$$Y = 4.048 * X1 + 3.765 * X2 + 2.825 * X3 + 1.880 * X4 \quad (6)$$

$$Y = 3.840 * X1 + 2.383 * X2 + 2.976 * X3 + 1.870 * X4 \quad (7)$$

$$Y = 3.527 * X1 + 4.055 * X2 + 1.137 * X3 + 1.509 * X4 \quad (8)$$

$$Y = 4.760 * X1 + 2.880 * X2 + 1.251 * X3 + 1.691 * X4 \quad (9)$$

$$Y = 4.695 * X1 + 2.985 * X2 + 2.394 * X3 + 1.969 * X4 \quad (10)$$

$$Y = 3.558 * X1 + 4.824 * X2 + 3.708 * X3 - 1.102 * X4 \quad (11)$$

$$Y = 4.459 * X1 + 5.415 * X2 + 1.554 * X3 - 0.932 * X4 \quad (12)$$

It is worth noting that b1 and b2 coefficient values are the highest for all cases, meaning that the number of deliveries made by the BBFCC is strictly related to the number of articulated vehicles and 18-tonne vehicles that deliver to the BBFCC. It can be explained through reference to the vehicles' load factors: articulated vehicles and 18-tonne vehicles understandably have a higher load factor than the other vehicles in the analysis. so a higher number of deliveries to the retailers could be expected if the size of the delivery made to the UFFC is related to the size of the vehicle making the delivery.

Generally, it can be said that every articulated vehicle that makes a delivery to the BBFCC generates on average from 3 (3.558 on Fridays) to 5 (4.76 on Tuesdays) deliveries from the BBFCC to the retailers; every 18-tonne vehicle that makes a delivery to the BBFCC generates on average from 2 (2.383 in the period January-May) to 5 (5.415 on Thursdays) deliveries from the BBFCC to the retailers; every 7.5-tonne vehicle that makes a delivery to the BBFCC generates on average from 1 (1.137 on Mondays) to 4 (3.708 on Fridays) deliveries from the BBFCC to the retailers; every van that makes a delivery to the BBFCC generates up to 2 (1.969 on Wednesdays) deliveries to the retailers. Also, the maximum coefficient value is 5.415, corresponding to Case 9 and variable X2, hence the number of stores visited on Thursdays is strictly related to the number of 18-tonne vehicles which make deliveries to the BBFCC. On the other hand, it can be noted that b4 assumes a negative value (-0.932) for the same case, suggesting that the number of stores visited is essentially independent of the number of van-based deliveries to the BBFCC on Thursdays. The minimum coefficient value is -1.102, associated with Case 10 and variable X4: so the number of deliveries made by the BBFCC is almost independent of the number of vans that make deliveries to the consolidation centre on Friday. For the same day, the highest coefficient value is related to 18-tonne vehicles.

Generally speaking, deliveries to the retailers are not closely related to the number of vans that visit the BBFCC. but on the contrary there is a high correlation between the onward deliveries from the BBFCC and the number of articulated and 18-tonne vehicles which deliver to the BBFCC.

The difference between b1 coefficient values for all cases is not high, but more-or-less constant. On the other hand, the difference among b4 coefficient values is high, ranging from 1.969 to -1.102. The highest influence that vans have on deliveries made from the BBFCC is on Wednesdays (in case 8 the highest b4 value is recorded).

Two negative coefficient values are achieved for deliveries made by vans on Thursday and Friday. The results indicate that the van variable and the number of deliveries made to the retailers in the Bristol shopping centre are inversely proportional, hence deliveries made by BBFCC can increase on Thursday and Friday by decreasing the number of vans that deliver to the consolidation centre. This looks like a dubious result; in fact, t-values for these cases show that there is no correlation between X4 and Y, because for these values there is not enough statistical evidence to reject the null hypothesis. (The null hypothesis, H0, is the statement that is assumed to be true at the start. and then should be checked to be confirmed or rejected. The hypothesis H1 is known as the alternative hypothesis. In this case the null hypothesis is "there is a correlation between Y and X4"). It can be concluded that deliveries made by BBFCC on Thursday and Friday do not depend on the number of vans that deliver to BBFCC on those days. So, do not considering vans for case 9 and 10, the analysis spawns the following equations for case 9 and 10 respectively:

$$Y = 4.564 * X1 + 5.169 * X2 + 0.853 * X3 \quad (13)$$

$$Y = 3.558 * X1 + 4.278 * X2 + 3.254 * X3 \quad (14)$$

R square adjusted value is 0.893 for case 9 and it is 0.919 for case 10; however, t statistics values are not within targets for case 9, but they are appropriate for the following equation, which considers only articulated vehicles and 18 tons vehicles:

$$Y = 5.000 * X1 + 5.186 * X2 \quad (15)$$

R square adjusted value is 0.892 for equation (15). It suggests a better variable correlation for equations (14) and (15) and they can be assumed as the most appropriate for Thursday and Friday delivery days respectively.

About the emissions results shown in table 4, the highest contribute to total CO2 reductions are represented by June 2011 and January 2012; on the other hand, April and June 2011 represent the highest contribution rate to the total NOx reductions, July 2011 and January 2012 represent the highest to PM10 reductions and April and July 2011 together with the month of January 2012 to CO reductions.

7. Conclusions

Users of the BBFCC reduced the number of deliveries they received by 74% and none dropped out during the project, but take-up was lower than targeted. However, although the emissions reductions are potentially significant, they are currently limited by small scale. The model constructed for deliveries to Bristol via the BBFCC showed high correlation coefficient values (over 85%). The most suitable model had the interception value equal to zero, indicating that the most effective design for the BBFCC is a cross-dock approach. The linear regression model highlights the high correspondence between the number of articulated and 18-tonne vehicles that made deliveries to the BBFCC and the number of deliveries made to the retailers from the BBFCC.

Emissions reductions in Bristol are identified as a result of sharing delivery vehicles for the final leg. 28,677 Kg of CO2, 122.29 Kg of NOx, 2.31 Kg of PM10, 20.32 Kg of CO and 9,854 Kg of fuel were achieved thanks to BBFCC for the whole period. However, due to out-of service time of the electric vehicle, it was substituted by a diesel vehicle to make the deliveries and so reductions could have certainly been higher if the deliveries had been made by electric vehicle only. Specifically, if compared with the polluting emissions and fuel reductions indicated in table 4, it would be achieved an increase in CO2 reduction by 8.74%, in NOx reductions by 10.03%, in PM10 reduction by 8.59%, in CO reduction by 11.54% and in Fuel reduction by 8.74%.

As it is shown in table 4 (both Real and Hypothetic case) it is worth noting that January, June and March give highest contribution rates to the total reductions values. It can be explained by seasonality reasons (Easter, Winter and Summer sales). This aspect could be considered maybe by introducing new seasonality variables.

About the reduction in the number of HGV movements avoided in Bristol city centre in the study period, it has been achieved a mean of 75.5% with a peak value of 80.19% in April 2012. The linear regression models developed

provide a useful tool for local authorities and logistics/transport planners in optimising the planning of UFCCs to reduce freight traffic and associated emissions.

Logistics operators can reorganise the UFCC logistics asset by means of a new weekly-delivery-plan that can change week by week by considering the type and the number of HGVs that are expected to the UFCC week by week; hence they can reduce costs and improve the UFCC performance. On the other hand, local authorities can forecast the positive effects related to the HGVs avoided to the city centre and the related polluting emissions reductions.

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